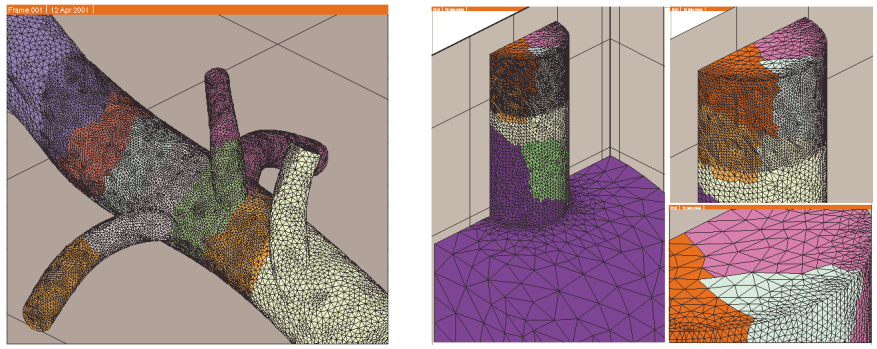
PYRAMID Parallel Unstructured Adaptive Mesh Refinement Library

PI: Dr. Charles D. Norton, Jet Propulsion Laboratory, California Institute of Technology

Objective

- Develop an advanced software library supporting parallel unstructured adaptive mesh refinement (AMR) for large-scale scientific & engineering applications with complex geometries (e.g., finite element modeling).
- AMR significantly reduces the time to solution for large-scale applications with widely varying and evolving resolution requirements. Our tool will provide unprecedented power, completeness, and ease of use (particularly for the Fortran community) where numerous complex solvers already exist.



Unstructured Mesh Examples

Approach

- Work closely with application teams to identify needed requirements to support solvers.
- Extend Pyramid to satisfy solver-driven requirements.
- Use GeoFEST (a finite element earthquake fault modeling code) to drive requirements on implementation

Key Milestones

• Boundary Condition Structure.	12/02
• Solver selection and requirements for analytical study.	2/03
• Integrate solver with Pyramid for analytical study.	5/03
• Integrate GeoFEST with Pyramid.	6/30
• Solver driven AMR for analytical study problem.	9/03
• Coarsening Algorithms & Various Code Improvements	2/04
• AMR for GeoFEST on fault stepover geometry.	6/04
• Final Software Delivery	9/04

Partners: A.Donnellan/JPL, M.Bhat & D.Spicer/GSFC

TRL_{in} =4

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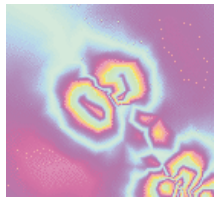
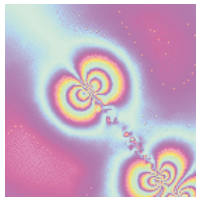
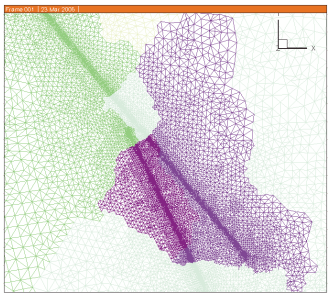
- Develop an advanced software library supporting parallel unstructured adaptive mesh refinement (AMR) for large-scale scientific & engineering applications with complex geometries. AMR significantly reduces the time to solution for large scale structural problems. Our tool will be modern, simple, efficient, and scalable for large-scale parallel finite element analysis.

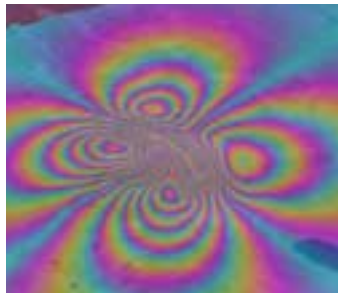
Use of PYRAMID in Quakesim Solid Earth Modeling Project





PYRAMID improves solution quality with higher resolution meshes (80K and 1.4M elements respectively)





Adaptive Mesh & InSAR fringe map of High-Resolution surface displacement from 16M AMR simulation of Landers Earthquake

Accomplishments

- Developed and released, via Open Channel Foundation, a publicly available parallel unstructured AMR library that is one of only a small handful of tools in this area.
  - PYRAMID provides unique features such as automatic mesh quality control and high-level library routines for easy integration into Fortran-based solvers using an object-oriented design methodology based on Fortran 90/95 in 3D.
- Ported to multiple platforms including Intel Pentium 4/Xeon, Apple G4/G5 Xserve, and SGI Itanium Altix clusters.
- Key achievements:
  - Orders of magnitude improvement in mesh size & time to solution for ESTO/CT Quakesim project simulations.
  - Over 100 downloads for use within laboratories, corporations, and universities. (i.e. MIT, Caltech, Japan National Institute of Advanced Industrial Science and Technology)

CoIs: Dr. John Lou & Dr. E. Robert Tisdale, JPL/Caltech **TRL_{in} =4; TRL_{out}=6**

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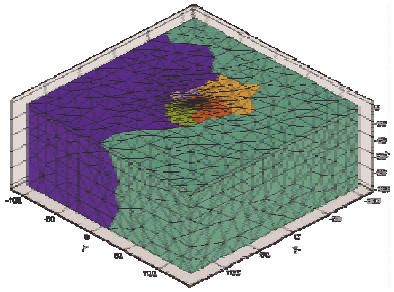
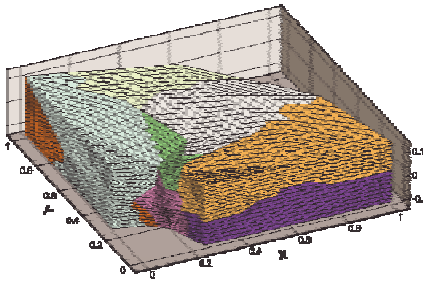
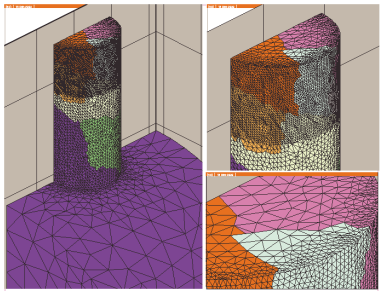
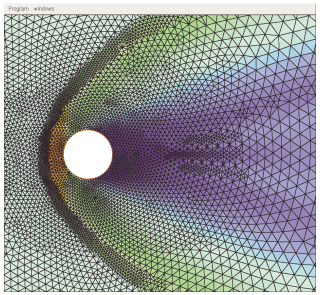
Modern... Simple... Efficient… Scalable...









Purpose and Usage of Pyramid

Fast parallel mesh generation & library to convert sequential FEM solvers for parallel systems adding solution-adaptive refinement for scientific & engineering modeling simulations.

Notable/Unique Capabilities

- Efficient object-oriented design in Fortran 90/95 and MPI
- Automatic mesh quality control, dynamic load balancing, mesh migration, partitioning, integrated mathematics and data accessibility routines, easy solver integration
- Scalable to hundreds of processors and millions of elements for 3D tetrahedral mesh problems
- Power and ease of use

Future Required Capabilities

- Mesh coarsening, parallel I/O, commercial mesh generation formats, web-based training, infrastructure enhancements

Comparison to State-of-the-Art

SUMMA3D (ANL) is the only other recognized parallel F90/95-based unstructured library code, but work in 3D is on-going and mesh smoothing (post-refinement geometry corrections) is used rather than dynamic mesh quality control. PAOMD (Rensselaer) includes refinement & coarsening, but use of C++ has not appealed to the Fortran-based solver community.

NASA and ESTO/CT Relevance

Large scale modeling and simulation applications with complex geometry including support of ESTO/CT Round III Quakesim Solid Earth active tectonics modeling team.

Other Relevant Application Areas

- Structural modeling and engineering mechanics for Earth and Space science applications
- Fluid mechanics, space gas dynamics, microwave devices

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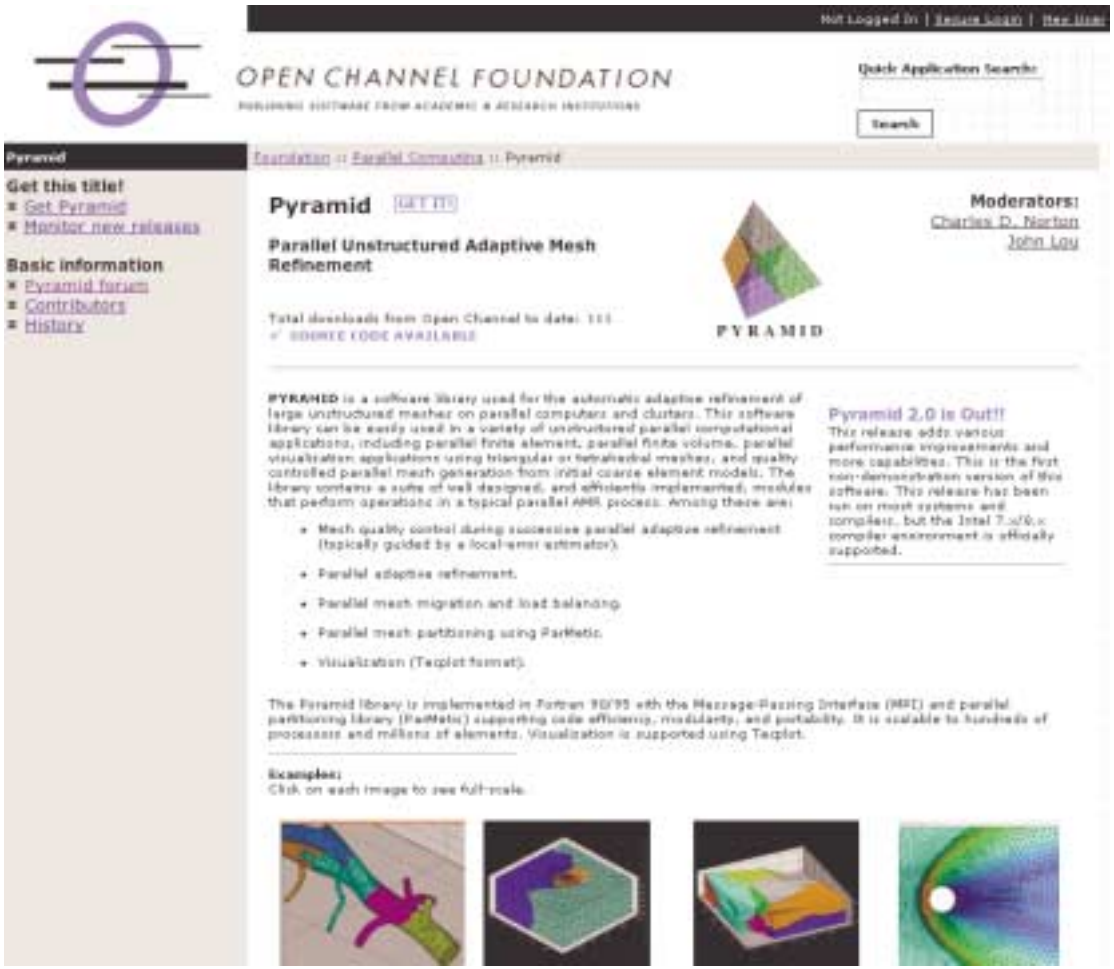
Primarily used for parallel geophysics and mesh generation since official manual was recently released



Current Users	Application
MIT USA	Geophysics
Caltech/JPL USA	Geophysics, Radar Mesh Generation
Technical Edu. Inst. Greece	Geophysics
University of Aachen Germany	Geophysics
New Users	**Application**
Arnold Engineering USA	Fluid Dynamics
U. Mass-Dartmouth USA	Coastal Ocean Modeling
Inst. Aerospace Eng. China	Fluid Dynamics
SUPREAO France	Shock Dynamics

#1 tool listed by Google search engine for parallel unstructured AMR

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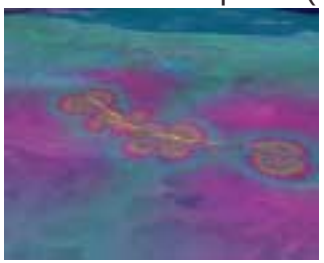
Earthquake Simulations and Performance

Landers fault model showing synthetic observable time-dependent surface deformation using GeoFEST parallelized with Pyramid

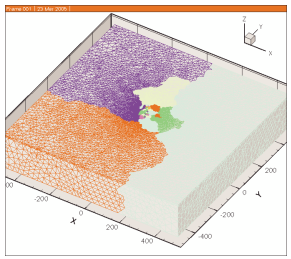
In-Sar fringes of surface uplift from Landers earthquake (1.4 M elements)

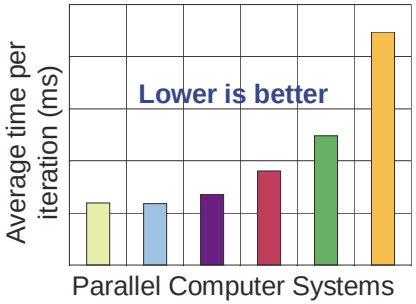


Instantaneous coseismic vertical deformation

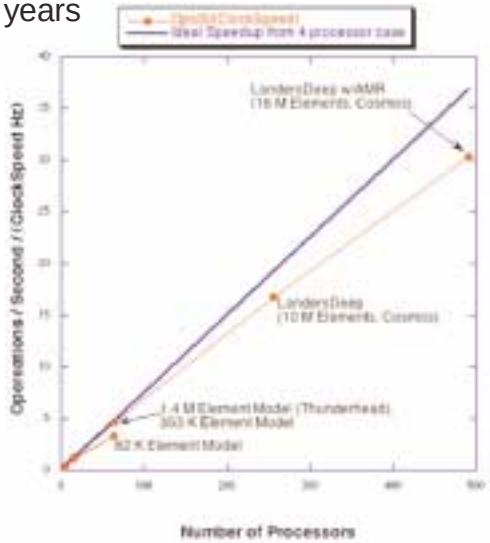
Postseismic viscoelastic relaxation at 500 years

16 M element mesh





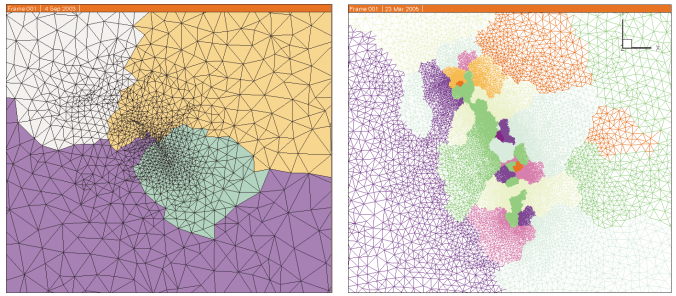
- Apple 2.0 GHz PPC G5 (Infiniband)
- Intel 3.0 GHz Pentium IV (GigE)
- Intel 2.4 GHz Pentium Xeon (Myrinet)
- SGI 1.5 GHz Altix 3000 (NUMA)
- HP 1.0 GHz Itanium 2 (QsNET)
- Apple 1.0 GHz PPC G4 (GigE)

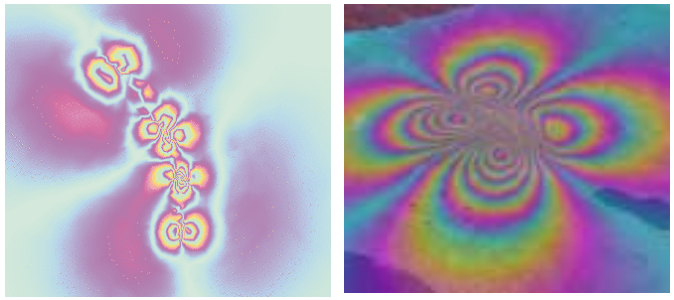


Adaptive Methods

Use of strain energy to drive adaptive re-meshing to improve solution quality has been demonstrated

Landers 3D finite element mesh partitioning





Impact of high resolution meshing on solution quality 80 K element mesh (L) and 16 M element mesh (R)

Impact

Potential to forecast seismic events utilizing data from space and ground based instruments coupled to multi-resolution advanced simulation models